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Date of request 12/8/95 Expected receipt of document 1/8/95

Document number KP-1633 supplement / DEL Date of document ~~2/16/59~~ 5/14/59 (DOES NOT INCLUDE APPEND A except for 2 pgs)

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Note: Appendix A is a Westinghouse Report (except for 2 pages) and this document will be reviewed by J. Lamb to determine if still needed.

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Date request received 12/12/95

Date submitted to ADC 1/5/96

Date submitted to HSA Coordinator 12/12/95

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Date submitted to CICO 1/5/96

Date received from CICO 1/24/96

Date submitted to ChemRisk/Shonka and DOE 1/25/96

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KP-1633
Supplement

FINAL REPORT OF POWER INTERRUPTION[illegible] TO OAK RIDGE GASEOUS DIFFUSION PLANT[illegible] GENERATING STATION OF JANUARY 17, 1959

K-25 RC

OAK RIDGE GASEOUS DIFFUSION PLANT

operated by

UNION CARBIDE NUCLEAR COMPANY
DIVISION OF UNION CARBIDE CORPORATION

for the Atomic Energy Commission

RESTRICTED DATA [illegible] document contains restricted data [illegible] defined in the Atomic Energy Act of 1954. Its transmittal or the disclosure of its contents in any manner to an unauthorized person is prohibited.

[redacted]

Date of Issue: May 14, 1959

Report No.: KP-1633
Supplement /DEL

FINAL REPORT OF POWER INTERRUPTION TO OAK RIDGE GASEOUS DIFFUSION PLANT GENERATING STATION OF JANUARY 17, 1959

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FINAL REPORT OF POWER INTERRUPTION TO OAK RIDGE GASEOUS DIFFUSION PLANT GENERATING STATION OF JANUARY 17, 1959

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Introduction

An electrical fault in an induced-draft fan motor at the Oak Ridge Gaseous Diffusion Plant Generating Station occurred at 4:20 p.m. on January 17, 1959, and although the 2300-volt circuit breaker to the fan motor interrupted the motor fault successfully, a second fault was initiated on the auxiliary transformer No. 2 secondary breaker feeding the 2300-volt bus. Due to the absence of any bus or breaker protection, this second fault continued for two minutes before arcing into the zone protected by the auxiliary transformer differential relays. The action of these relays caused both high-side and low-side auxiliary transformer breakers to open, but due to induced overvoltages and deteriorated solid insulation one of the two high-side (13.8kv) breakers faulted on opening and this failure led to the shutdown of the K-25 portion of the ORGDP cascade at 4:28 p.m. Power was restored forty-four minutes later at 5:12 p.m., but the interim power failure to the instrument air compressors also caused a brief shutdown of the K-29 and K-33 buildings and a portion of K-31.

The fire damage is estimated to have been $86,020, although necessary repairs and replacements will cost a lesser amount, $64,980, since some of the damaged equipment will not require replacement. An additional cost of $25,554 was spent for major cascade equipment maintenance as a result of the power and instrument air failures.

A detailed description of this incident has been presented in the investigating committee's interim report*. This final report presents subsequent findings of continued electrical system investigation and associated engineering studies made by and for the committee appointed to investigate this incident. A final review of the over-all conclusions and recommendations of the committee is also contained herein. These recommendations call for a total expenditure of $166,975 for system improvements.

Summary of Findings

The original design of the K-25 electrical system was based on the urgency for continuity of operation and the reliability of the power supply. Consequently, protective tripping devices were held to a minimum, accepting the remote risk of equipment fault damage. This expressed philosophy or criteria has proven successful over fifteen years of K-25 operation; nevertheless, in view of the subject incident, the committee's attention was directed primarily at modern engineering techniques and their economical application to K-25 for

*Interim Report of Power Interruption to Oak Ridge Gaseous Diffusion Plant Generating Station of January 17, 1959, KP-1633, Dated February 16, 1959.

[redacted]

Summary of Findings - Continued

improved fault protection without appreciably reducing the system reliability.

The committee made additional investigations and consultations following the issuance of the interim report, and the added information confirmed the previous findings. Some aspects of this incident were found to be quite unique in industry in that similar occurrences could not be found and the cause for the failure could not be precisely determined. Other aspects were found to be more common and were more easily verified.

The failure of the induced-draft fan motor, which seems to have been the initiating cause of the subject incident, can be attributed to normal aging of the insulation. This motor had been in almost constant operation since 1944. However, because only "instantaneous-overcurrent" relaying, set at nine times full load current to prevent breaker tripping on normal start-up, was installed for these motors, the initial motor fault had to develop into a severe fault before being isolated automatically. This resulted in greater damage to the motor than would have resulted had "time-overcurrent" or "thermal overload" relaying been installed. It also permitted the arcing in the motor to continue for a longer period of time and thereby have greater opportunity to produce overvoltages on the system. The development of the motor fault into one of large magnitude also increased the possibility of creating switching surges of maximum amplitude.

The cause for the failure of the 2300-volt auxiliary transformer breaker, which supplies power to the bus feeding the faulted induced-draft fan motor, cannot be determined except in a general way. The breaker was not called upon to operate until after the breaker was almost completely destroyed. Since this breaker was given a thorough overhaul less than a year before its failure, at the same time when other breakers on this bus were overhauled, and since this breaker had not been operated since its overhaul, there seems to be absolutely no reason to suspect lack of or improper maintenance to be the cause of failure. All of the breakers were operated well within their current rating. The manufacturer has stated that it is his opinion the failure was caused by deterioration of the solid insulation and the presence of transient overvoltages on the bus. Most types of overvoltages subject all parts of a network to the same voltage stresses, but some "steep-fronted" transient voltage waves are reflected from high impedances, such as transformers, and it is possible that the transformer secondary breaker was subjected to a combination of these transient overvoltages that the rest of the electrical system did not experience.

The cause for the failure of the 13.8-kv air circuit breaker, 53-E, which supplied power to auxiliary transformer 2, was also given by the manufacturer as a combination of deteriorated surface insulation of the Micarta parts of the breaker and the presence of transient overvoltages. Since this failure, all of the thirteen breakers on 60-El bus have been completely overhauled and some evidence of insulation deterioration was found, supporting the Westinghouse explanation. Most of the deteriorated surface insulation was found on

[redacted]

Summary of Findings - Continued

the blast tube support struts and the blast tubes, but was not apparent in most cases until after the varnish was sanded from the parts.

The committee determined that the severity of the induced-draft fan motor, 2300-volt transformer secondary breaker, and the 13.8-kv transformer primary breaker failures were much greater than would have been experienced had better relay protection been available.

The instrument air, which is normally supplied from the K-25 air plant, failed as a result of the K-25 power failure, the mechanical "hanging" of the starting switch to the first-stage emergency instrument air compressor at the K-25 air plant, and the inability of the K-33 stand-by instrument air compressor to supply the total load by itself.

Summary of Conclusions and Recommendations

A. Power System

The failure of the induced-draft fan motor was apparently the result of normal deterioration of the stator winding insulation, as the motor had been in operation for approximately fifteen years. The severe damage to both the high-speed and low-speed windings was attributed to the lack of "time-overcurrent" or "thermal overload" relaying. Since this type of relaying would have tripped the motor breaker when the insulation failure first developed into a major fault, the damage to the motor would have been greatly reduced. Also, the chance for the initiation of overvoltages on the system would have been reduced. Therefore, the committee recommends that overload relays be installed to protect the induced-draft fan motors and all other 2300-volt motors at the powerhouse and the rest of ORGDP. The best present-day relay design schemes make such relaying a normal part of all installations being built.

Without being able to furnish positive proof, the committee feels that a major factor in the initiation of the fault in the auxiliary transformer secondary breaker was the fact that the 2300-volt system was not grounded. There are numerous cases in the literature where similar multiple failures have been experienced on ungrounded systems. Westinghouse Electric Corporation, the manufacturer of the faulted switchgear, has stated that transient overvoltages were a major factor in initiating this failure and that these transients could have been moderated to values within the capacity of the insulation had the system been grounded. The General Electric Company has been an advocate for the past several years of system grounding and has maintained that more frequent and disastrous failures occur on ungrounded systems than on grounded systems. The committee, therefore, recommends that the 2300-volt systems at the powerhouse and at other locations in the Oak Ridge Gaseous Diffusion Plant be grounded and associated alarm annunciation be provided. The K-29 process 480-volt networks should also be grounded since failures apparently caused by transient overvoltages have

[redacted]

Summary of Conclusions and Recommendations

A. Power System - Continued

been experienced on these systems. After careful study and investigation, the committee feels this grounding can be most economically affected by utilizing the "high-resistance" design for application to these "delta-connected" systems.

The committee found that the maintenance and testing practices employed at ORGDP were in accordance with the instructions of the manufacturer and followed normally accepted industrial standards. However, the committee recommends that the 15-kv a-c high potential test recently suggested by the manufacturer, or similiar insulation tests, be made a part of the routine inspections of the 2300-volt breakers. Such tests would be the most sure method of locating any deteriorated insulation, since all of the insulating surfaces cannot be visually observed, and even where the surfaces are exposed, the defects are not easily detected.

The magnitude of the damage to the 2300-volt switchgear was determined to be caused by the absence of protective relaying for the transformer secondary breaker and the 2300-volt bus. The committee recommends that the transformer differential relaying scheme be modified to include the secondary breakers in the protected zone and that time-overcurrent relays be installed on each secondary breaker to provide protection in case of bus or feeder breaker faults. The committee also recommends the installation of residual ground relays to improve the protection of the high-voltage windings of the auxiliary transformers and auxiliary lock-out relays to prevent the automatic transfer of the spare auxiliary transformer to a faulted bus. These additions are presently accepted practices which were not made a part of the original installation.

The primary cause for the failure of the 13.8-kv breaker on the high-side of auxiliary transformer 2 was degenerated insulation. The existence of transient overvoltages may have contributed significantly to the failure. It is therefore recommended that adequate means be developed for detecting these declines in insulation strength and that such measures be made a part of the routine maintenance and inspection procedures. The 37.5-kv a-c high potential tests (recently suggested by the manufacturer), 40-kv d-c high potential tests, and Doble "power factor" tests--all of which are currently being tried--appear to be applicable. Whenever any of these tests, or visual inspections, indicate that the Micarta insulation has deteriorated appreciably, these parts should be revarnished to bring their insulation strength back to normal. The committee recommends that, except for this additional insulation test following overhaul, the overhaul and testing procedures should be continued as in the past.

The presently installed ground-fault bus relaying for the 60-E1 bus would normally have isolated the fault in ACB 53-E and have limited the damage to

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Summary of Conclusions and Recommendations

A. Power System - Continued

a fraction of that experienced. In metalclad switchgear such as that installed at the K-25 Switchhouse, where each of the three phases is segregated in steel compartments, faults have to initiate as phase-to-ground failures and no other failures have been experienced to date which were not isolated by the ground-fault bus relaying, where it was applicable, before extensive damage was done. However, in this case faults on each of the three phases developed within two cycles and it is doubtful if any available ground-fault bus protective scheme would have operated fast enough to isolate this fault. The operating time of the present ground-fault bus relaying has been reduced to the minimum possible, which is slightly more than two cycles, and no additional change to this relaying is considered advisable. However, voltage-restrained, time-overcurrent and negative sequence relays should be installed on the generators to provide external-fault back-up protection for bus faults. If these relays had been installed on generators 6 and 7 before the January 17 failure, these units would have tripped out of service, the damage to ACB 53-E would have been minimized, and ACB 54-E would probably not have been damaged at all. The committee noted during its investigation that the "variable frequency" (K-25 process) and "ring" buses were installed without any bus protection, and it recommends that ground-fault bus protection be installed where the bus and breaker cubicles can be economically insulated and that differential relaying be installed where this is not feasible. Faults resulting in greater damage to equipment than was experienced on January 17, 1959, are possible without this relaying.

The cost to make all of these improvements to the ORGDP power system will total $143,560.

Additional details and reference data of the committee's investigation into the electrical aspects of this incident can be found in the attachment to this report and in the interim report.

B. Instrument Air System

The failure of the reduced-voltage motor starter to the first-stage emergency air compressor, due to mechanical hanging, was found to be the result of equipment deficiency and not attributable to inadequate or faulty maintenance. Following the failure, the cause for this equipment to fail to operate properly was thoroughly investigated. It was found that the diesel-generator voltage dropped enough when the first stage compressor started that the voltage was insufficient to hold the motor starter in the closed position and the starter would open and then reclose. This situation had undoubtedly existed since installation, but since the equipment was enclosed and there was a very high noise level in the building, the reopening of the starter could be neither seen nor heard. Since it had indicated satisfactory operatio on the 55 or more test runs made prior to this failure, there was no suspicion

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Summary of Conclusions and Recommendations

B. Instrument Air System - Continued

that any deficiency existed. An effort has been made to improve the operating dependability of the switch to a satisfactory level. Weekly operational tests will be made on this emergency equipment and the action of the breakers observed through the new Plexiglass cubicle covers. If satisfactory and consistent operation of these breakers is not obtained during future tests, the switchgear should be replaced with equipment of a more dependable design.

Since the instrument air system is so vital to the operation of the entire cascade, the committee recommends that additional provisions be made to insure an adequate power supply. The most logically means of accomplishing this aim still appears to be those outlined in the interim report, as follows:

1. Provide alternate utilization of diesel power via manual switching on four 730 cfm Worthington reciprocating compressors.

2. Provide alternate power source to normal compressors from K-27. (This feeder would also serve the K-802 Recirculating Water Plant and the K-1501 Steam Plant with an alternate source of power.)

To accomplish these two improvements an expenditure of $23,415 will be made. Additional details and reference data of the instrument air failure portion of this incident can be found in the attachment to this report and in the interim report.

C. Cascade

It is the conclusion of the committee that the emergency equipment installed following the 1950 power failure, and the emergency procedures developed since that time were proven to be effective and adequate for handling such emergencies, and that no expenditures for improvements appear to be warranted at this time.

Additional details and reference data of the cascade operations associated with this incident can be found in the attachment to this report and in the interim report.

D. Fire Control

Fire fighting activities in the switchhouse galleries were made extremely difficult by the lack of ventilation during the power failure, and the absence of floor drains for removing the fire water from the switch galleries delayed the return of the electrical systems to service. These two problems have received considerable attention from the committee. All schemes proposed

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Summary of Conclusions and Recommendations

D. Fire Control - Continued

to date for handling these problems have required large outlays of funds which the committee did not feel was justifiable. Study of these problems will continue by operating and fire control personnel and any improvements which appear economically sound can be effected through normal channels.

This final report was prepared under the supervision of and has been reviewed in detail by the Investigation Committee. Approval of its content is indicated by signatures of individual committee members below.

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Oak Ridge Gaseous Diffusion Plant

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[redacted]

[redacted]

ELECTRICAL SYSTEM INVESTIGATION

I. Review of Original Design Philosophy and Application

When the original K-25 cascade and powerhouse were built, the United States of America was in the midst of World War II. It was not known whether or not the gaseous diffusion process would be a practical or economic method of separating uranium isotopes. "Time" was the most important consideration in making all decisions, and any elaborate design which was not essential or which might complicate or frustrate the primary aim of producing bomb material in the shortest possible time was eliminated. This central idea might be stated as insuring maximum reliability of initial operation. This led to the elimination of some of the normally applied relay protection, since false relay operations might result in unnecessary shutdowns of vital equipment.

The continued necessity for an extremely reliable power supply and the fact that the K-25 and K-27 cascades and the powerhouse have operated so remarkably well, made it difficult to justify the expenditure of vast sums of money for "improvements" for which no need was evident. The K-25 and K-27 process 480-volt networks, as well as others, still do not meet some normally-accepted, present-day practices. Although the committee recommends that these conditions be studied to make sure that there is at least one "line" of protection for all possible faults, which can be obtained by adjustment of existing equipment or installation of minor additions, the committee could not see the wisdom of modifying this equipment to conform to these practices because of the large number of systems involved, and the lack of any experienced difficulty in fifteen years of operation.

II. Review of Failure Causes

The primary cause of the failure of the auxiliary transformer No. 2 2300-volt secondary breaker is believed to be transient overvoltages, which could have been moderated to levels within the ability of the insulation to withstand had system neutral grounding been employed on the 2300-volt bus.

The principal cause for the failure in the 13.8-kv high-side breaker to auxiliary transformer No. 2 appears to be due to deteriorated surface insulation on the Micarta parts of the breaker. In both of these faults, as well as in the induced-draft fan motor failure, the resulting damages were much more extensive than would have been experienced had better relaying been installed. The reasoning behind these conclusions, and other pertinent information accumulated by the committee during the course of its investigation is presented in the following sections.

III. Equipment Examination and Tests

All of the 13.8-kv air circuit breakers (ACBs) on 60-E1 bus, including the replacements for ACB 53-E and 54-E, were completely overhauled following the failure on January 17. Numerous cases of deteriorated solid insulation were discovered. Two wooden operating rods were found to have had leakage paths along

[redacted]

III. <u>Equipment Examination and Tests - Continued</u>

the surface from one end to the other. Approximately half of the blast tube support struts had some surface tracking, apparently caused by corona, and about one-third of the blast tubes had a small amount of corona tracking on the outside surfaces, principally near the grounded end of the blast tubes. An extreme example of deteriorated surface insulation on struts is shown in Photograph One. The two sides of the left strut shown in Photograph One are shown in Photographs Two and Three. Photograph Three shows how the destruction of the insulation progresses after leakage paths like those in Photograph Two have been established. It should be pointed out, however, that it is reasonably certain that most of this surface breakdown developed after the fault in ACB 53-E occurred. The fires in ACBs 53-E and 54-E produced voluminous quantities of thick black smoke which settled on all surfaces in the gallery, including the solid insulating parts inside the breaker cubicles. When the fires were still being fought, some of the breakers were energized from one side and arcing inside the breakers was noted. ACB 50-E, shown in Photograph One, was one of these breakers. If a breaker were energized with the Micarta insulation parts heavily coated with a carbonaceous dust, severe and wide-spread tracking could be expected to develop. Although it is undoubtably true that most of the observed insulation deterioration happened after ACB 53-E failed, these cases clearly point out how fast and completely insulation can fail if the surfaces become contaminated with conducting materials, and emphasizes a cardinal point in maintenance of electrical insulation to "keep it clean". Three cases of corona tracking were discovered on arc chutes, and they are shown on Photographs Four, Five, and Six.

All of the breakers on 60-E2 bus are to be overhauled in the near future in the same manner as was followed for the breakers on 60-E1 bus. It is believed that the condition of the insulation in the breakers on 60-E2 bus is typical of the condition which was present on the breakers on 60-E1 bus before the January 17 failure. Any insulation deterioration which exists in the breakers on 60-E2 bus will be found during the sanding of the Micarta parts prior to revarnishing. 37.5-kv a-c high potential tests, 40-kv d-c high potential tests, and Doble power factor tests will be made before and after the overhaul of these breakers and the results compared with the findings of the condition of the insulation during the reworking of the breakers. It is hoped that at least one of these three insulation tests will be proven to be effective in accurately measuring insulation damage, and predicting when insulation breakdown is imminent so that corrective measures can be made prior to the initiation of faults. From all the information the committee has been able to obtain, it is apparent that very little work has been done in this field, and only one company was found which periodically makes insulation tests on air circuit breakers.

Four failures have been experienced in K-31 on air circuit breakers of the same general type as the 13.8-kv breakers which failed on January 17. These K-31 breakers are new models of the original Westinghouse CA breakers installed in the K-25 and K-27 switchhouses. The first failure occurred in 1954, two occurred in 1956, and the last one occurred in 1958. All of the failed breakers were power transformer secondary breakers and the failures occurred on normal opening cycles when the breakers were carrying a current slightly less than half

[redacted]

III. Equipment Examination and Tests - Continued

of the continuous full load rating of the breaker. Discussions with the manufacturer were instigated following the first failure in 1954 and further investigation following the 1958 failure was in progress to try to determine the cause or causes for these faults when the subject failure occurred on January 17. It was the feeling of the committee that there may have been a correlation between the trouble experienced on breaker 53-E and the failed ACBs at K-31. Due to an improvement in the relaying scheme at K-31 before the last failure there, the breaker sustained only minor damage, and the committee hoped that by a vigorous pursuit of the investigation of this last K-31 failure, the cause of the failure of ACB 53-E might well be found. This failure at K-31 had definitely been a ground fault through air from the movable contact on the center phase to the cubicle door. When several members of the committee met with Westinghouse personnel at East Pittsburgh, Pennsylvania on February 3, 1959, considerable time was spent in a discussion of these K-31 failures. The Westinghouse personnel were of the definite opinion that the K-31 failures were due to some unknown circuit condition, and had no relation to the failure of ACB 53-E. They requested that a number of oscillograms be made during the same type of normal opening cycles on which the failures had previously occurred. They suggested that the line-to-ground voltages on each side of the test breaker, as well as the voltage across the breaker and the line currents through the breaker, be recorded on oscillograms during the opening operations. Because of the possibility that high frequency voltage waves might not pass through the potential transformers and appear on the oscillograms, resistance voltage dividers were used to insure the fidelity of the results. Oscillograph galvanometers with good high-frequency response were also used to make certain reliable information was obtained. Forty-one oscillograms were made, with thirty-nine being made on opening cycles and two being made on closing cycles. The tests made on opening cycles were made under three different conditions of loading and all tests were performed on ACB 405, which was the last breaker at K-31 to fail. This breaker had required only the filing down of the contact parts where the arcing had taken place and the revarnishing of a burned spot on the blast tube following the failure, and since neither UCNC nor Westinghouse maintenance personnel could find any maladjustment or defect in the breaker, it was thought that this breaker, which was in the identical condition prior to its failure, would be a good test specimen. System conditions were likewise identical to those existing at the time of the last failure. No precautions were made to prevent a recurrence of the last failure, but none occurred, although enough tests were made to equal the number of normal operations of all transformer secondary breaker operations at K-31 over a two-year period, which has been the failure frequency rate. One of the oscillograms obtained from these tests is shown in Figure One and it is typical of the others. No abnormal conditions were found to exist, according to the evaluation of local personnel, but all of the oscillograms have been sent to Westinghouse for their study and comments.

No tests or inspections have been made on auxiliary transformer No. 1 or 3 2300-volt secondary breakers, since the failure on the breaker on transformer No. 2. These will be made as soon as the new breaker and cubicle are received and installed and auxiliary transformer No. 2 returned to service. The spare transformer can then be used to replace the other two transformers, one at a time, and

[redacted]

III. Equipment Examination and Tests - Continued

the 2300-volt breakers carefully examined for evidence of insulation breakdown or other defects which could account for the experienced failure. All three 2300-volt secondary breakers for auxiliary transformers 1, 2, and 3 have been similarly loaded and maintained, and any normal deterioration would be expected to have taken place at about the same rate on each of them.

IV. Results of Outside Consultations

An effort was made to obtain the benefit of other experienced and recognized authorities in the electrical field, regarding the causes of the failures experienced January 17, 1959. Due to the seeming similarity between the two failures in K-29 480-volt switchgear which occurred on October 30, 1958 and the failure of auxiliary transformer No. 2 2300-volt secondary breaker; as well as similarities between the four 13.8-kv failures at K-31 on power transformer secondary breakers and the failure of ACB 53-E, the causes for these additional failures entered into many of the discussions.

Summaries of the relative and pertinent information obtained through these consultations are presented below:

A. Westinghouse Electric Corporation

Since Westinghouse was the manufacturer of the 2300-volt, as well as the 13.8-kv switchgear which faulted on January 17, 1959, they were naturally the first outside organization which was contacted to obtain assistance in determining the causes for these failures. On two occasions, Westinghouse sent factory and district representatives to the plant for on-the-scene examination and discussion, and three members of the Investigating Committee visited the main offices of Westinghouse in East Pittsburgh, Pennsylvania. Following the February 3 meeting in East Pittsburgh, Westinghouse sent a report on February 12 summarizing their conclusions as to causes for the failures and their recommended changes. Some items were discussed during the East Pittsburgh meeting which were not mentioned in their report and which were considered by the committee to be highly pertinent. Therefore, the secretary of the committee wrote back on March 4 to Westinghouse concerning these items and their reply to this communication was sent on March 25, 1959. All three of these communications are contained in Appendix A of this report.

"The following is a summary of Westinghouse opinion expressed in response to questions from committee personnel: *

1. Both the 13.8-kv and the 2.3-kv failures were insulation failures.

* From page 2 of the February 12, 1959 letter from Westinghouse Electric Corporation, contained in Appendix A.

IV. Results of Outside Consultations

A. Westinghouse Electric Corporation - Continued

2. The 2.3-kv failure is believed caused by transient overvoltages developed by the combination of (a) ungrounded system, (b) many long (400 ft.) cables on bus, and (c) arcing fault in motor, which might have persisted for an extended time before motor breaker was tripped.

3. On the 53-E breaker, failure was most probably over the blast tube, from the moving contact hinge to ground. Cause is believed a combination of deterioration of insulation and transients originating on 2.3-kv side of transformer.

4. Incorrect mechanical operation was given as a remote possibility, not probable."

To reduce the possibility of future occurrences of equipment failures on the 2300-volt systems, they recommended that these systems be grounded, using the high-resistance grounding scheme and that improved relaying be installed to limit the amount of damage if future faults should occur. They also recommended that 15-kv a-c high potential tests be made on the 13.8-kv breakers, although this information is not included in their original written report. According to Westinghouse, these tests should enable the detection of any deteriorated insulation before breakdown becomes imminent.

B. General Electric Company

This company has been a stout advocate of system grounding for about the last ten years. Considerable subject information by the General Electric Company was available in printed literature, and additional reference was forwarded to the committee upon request. Their position is well illustrated by the following excerpts from the article "High Resistance Grounding for Industrial Power Systems" by Mr. D. S. Brereton, which appeared in the July and October, 1957 issues of Distribution.

> "Years of experience in many industrial fields have shown that ungrounded systems are not as reliable as grounded systems."

> "If the first ground fault is not a solid one, an arcing ground may develop, resulting in the overvoltage phenomenon previously described. This, in turn, rapidly hastens the probability of the second ground fault with a good possibility of many more at other points on the system. Although more alertness to detection and faster location of ground faults is being accomplished today in ungrounded industrial power systems, little can be done to remove the plague of overvoltages and resulting high costs of repairing insulation failures with the low reliability of service that goes with the ungrounded system. These, then, are the principal disadvantages of this type of system."

IV. Results of Outside Consultations

B. General Electric Company - Continued

"Today, the problem of motor and other equipment failures due to transient overvoltages is being given much thought and consideration since the repair expense per year has been shown to be high. Such failures can either be due directly to a particular period of high overvoltage or indirectly due to a long period of periodic transient overvoltages on the system which deteriorated the insulation. The answer to this problem is system neutral grounding. This restrains these overvoltages and adds longer life to system insulation than with an ungrounded system."

"The high resistance grounded system has the very great advantage over an ungrounded system of reducing transient overvoltages, thus lengthening the life of all the apparatus connected at that voltage level, but still requiring the same time and equipment to find ground faults as does the ungrounded system. The elimination of multiple failures caused by transient overvoltages inherently means that less apparatus is damaged resulting in much lower maintenance and replacement costs."

From these statements it can be seen that the General Electric Company firmly believes that operation of ungrounded systems is comparatively unsafe and uneconomical.

C. Giffels and Vallet

The committee had an opportunity on March 5, 1959 to meet with Mr. Neil Bjorensen, Chief Electrical Design Engineer for Giffels and Vallet. Mr. Bjorensen had worked on the designs of many of the process buildings at Oak Ridge, Paducah, and Portsmouth and he was questioned extensively by the committee as to the reasons for the differences in the electrical design at the three locations, especially with regard to system grounding. He explained that for the past few years there has been an increasing trend toward system grounding and that at the time the Portsmouth plant was built it had become almost standard practice to install 480-volt systems with solid neutral grounding. He also stated that in most of their design work, electrical systems are designed with grounded neutrals, although there were notable exceptions, principally in the automobile industry.

D. Sargent and Lundy

Mr. F. W. McCloska, Senior Electrical Design Engineer for Sargent and Lundy, was contacted by a member of the committee regarding present thinking in power station design with respect to the desirability of grounding powerhouse auxiliary circuits. He stated that there was a definite trend toward 4160-volt auxiliary systems which were wye-connected and grounded. This was prompted by the economies of the

IV. Results of Outside Consultations

D. Sargent and Lundy - Continued

larger size equipment being used today. The design of 480-volt systems varies, with some being ungrounded-delta systems and some grounded-wye systems, according to the manufacturers' or customers' preference.

E. Paducah Gaseous Diffusion Plant - UCNC

The electrical systems which supply power to the stage motors in all four process buildings at Paducah are grounded systems, which have voltage ratings of 2300-volt and 4160-volt. These systems are identical to the K-31 and K-33 process electrical systems at ORGDP. The 480-volt auxiliary circuits are ungrounded and there is one ungrounded auxiliary 2300-volt system. They have experienced no difficulty with these ungrounded systems to date. There had been a failure on a 13.8-kv Westinghouse type CA air circuit breaker at their C-533 Switchhouse in 1956 which they and Westinghouse engineers had concluded was caused by a crack in the Micarta blast tube. This crack was thought to have led to a reduction of surface insulation strength, through an accumulation of conducting particles, which resulted in a flash-over on that phase.

F. Portsmouth Gaseous Diffusion Plant - Goodyear Atomic Corporation

All electrical systems at the Portsmouth plant, whether 480-volt or 2300-volt, are wye-connected, grounded systems with the exception of one 2300-volt overhead line. The operation of these systems have been satisfactory in every respect.

G. American Electric Company

A member of the committee contacted the American Electric Company to inquire of their practices regarding the grounding of auxiliary systems in new powerhouse installations. They presently employ 4160-volt wye-connected, grounded systems and 480-volt delta-connected, ungrounded systems. The reason given for not grounding their 480-volt systems is that they have long used this type of design and feel that their experience with it has been very good; therefore, they see no reason to change.

H. Aluminum Company of America

Three members of the committee visited the Alcoa, Tennessee plants of the Aluminum Company of America on March 16, 1959. They had a number of 480-volt and 2200-volt systems which were ungrounded and which had been trouble-free for many years. They also had some 13.2-kv systems which were originally ungrounded. They had experienced one serious failure on a 13.2-kv system which they attributed to an intermittent arcing ground and had subsequently grounded these systems. They were seriously thinking of installing high-resistance grounding on some of

IV. Results of Outside Consultations

H. Aluminum Company of America - Continued

their 2200-volt systems and stated that 480-volt systems in a new generating station that they were planning to build would be wye-connected, grounded systems.

They were the only company contacted which owned 13.8-kv Westinghouse breakers of the same type that failed here on January 17. Although none of these breakers located in installations under their supervision had given any trouble, a failure had been sustained on one of these breakers at another one of the Alcoa plants and the manufacturer (Westinghouse) had similarly concluded that the failure was due to deteriorated insulation. This failure occurred last summer and at that time they had been advised by the manufacturer to perform 37.5-kv a-c high potential tests as a means of locating defective insulation prior to failure. None of these tests had been made on equipment located in the East Tennessee installations but Doble power factor tests had been made for the past few years and one defective ceramic insulator had been found.

I. Tennessee Valley Authority

The latest designs for auxiliary systems in TVA power stations utilize 4160-volt, wye-connected, grounded systems and 480-volt, delta-connected, ungrounded systems. They employ the 4160-volt, grounded systems for economical reasons associated with large equipment and the ungrounded, 480-volt systems because of excellent past experience with these systems.

This committee would like to acknowledge the fine interest and co-operation on the part of all the representatives of outside organizations that were contacted.

V. Engineering Studies for Relay Improvements

Deficiencies in relay protection for various parts of the ORGDP electrical system have been recognized for some time, with certain improvements budgeted and planned for this fiscal year. However, the magnitude of the faults in the 2300-volt and 13.8-kv switchgear emphasized the need for not only providing one "line" of protective relaying, but for providing "back-up" protection, especially where fault damage could be extensive. This was particularly true when considering the fact that the ground fault inside ACB 53-E developed into a three-phase fault so rapidly that the ground-fault bus relays did not operate, and this was the only relaying available to completely and immediately isolate the fault. An attempt has been made to thoroughly study the adequacy of the protective devices installed on the various electrical systems at the ORGDP power station and to recommend additions which seem economically justified. Relay improvements which seemed most warranted were investigated. Summaries of these relay investigations, including descriptions and cost estimates, are herein presented.

V. Engineering Studies for Relay Improvements - Continued

A. Relay Protection for Powerhouse 2300-Volt Motors

At the present time the only relay protection installed on the 2300-volt circuits which feed from the three auxiliary 2300-volt buses at the powerhouse is instantaneous overcurrent tripping. These relays must be set at approximately nine times the full load current on the motor circuits, to prevent undesirable trip-outs on start-up. Consequently, any fault must develop into a major failure before these relays will actuate to trip the breaker. The motors to powerhouse auxiliaries, such as boiler feed pumps, induced- and forced-draft fans, generator exciters, circulating water pumps, etc., are normally protected by time-overcurrent relays in addition to instantaneous overcurrent relays, as shown in Part A of Figure Two. The eighty-eight circuits at the powerhouse which need such protection could be equipped with these time-overcurrent relays for $35,030. The 2300-volt motors which power the air compressors and recirculating water pumps in the K-1101, K-802, and K-832 buildings need the same improvement in relay protection. This will cost an additional $15,750.

B. Auxiliary Transformer Secondary Breaker Overcurrent Relays

At the present time the 480-volt and 2300-volt auxiliary buses at the powerhouse have no relay protection. By installing time-overcurrent relays, with the current transformers located between the transformers and the secondary breakers, as shown in Part B of Figure Two, tripping would be insured for faults in the secondary or feeder breakers, or on the buses. This could be installed for approximately $7,400.

C. Differential Relaying for the Auxiliary Transformers

If time-overcurrent relays are installed for the secondary breakers, as described above, the existing set of current transformers between the auxiliary transformers and the secondary breakers can be used for this purpose. Then it would be highly desirable to install new current transformers between the secondary breakers and the auxiliary buses and use these current transformers in the differential relaying scheme for the auxiliary transformers. This would include the secondary breakers in the protected zone of the differential relays, as shown in Part C of Figure Two, and thereby overlap the breakers in the zones of protection for the auxiliary transformers and auxiliary buses, which is always considered good relay practice. The estimated cost to install these new current transformers between the secondary breakers and the buses is $8,750.

D. Lock-out Relays for Automatic Throw-over Schemes on Auxiliary Buses

An automatic throw-over scheme presently exists which closes the breaker to a bus from the spare transformer when voltage is lost on that bus. It would be desirable to install a lock-out relay to prevent such automatic

V. Engineering Studies for Relay Improvements

D. Lock-out Relays for Automatic Throw-over Schemes on Auxiliary Buses - Contd.

switching if the reason for the loss of voltage on the bus was the presence of a fault on that bus. This could be accomplished by preventing the closing of the breaker to the spare auxiliary transformer if the breaker to the normal transformer had tripped out on overcurrent, as shown schematically on Part D of Figure Three. The installation of these lock-out relays would cost about $1,530 for the three 480-volt and three 2300-volt auxiliary buses.

E. Ground Relays for High-Voltage Windings of the Auxiliary Transformers

The auxiliary transformers are presently protected by differential relaying, which is considered good protection, but it is somewhat insensitive at high loads. Sensitive ground relaying can be installed for approximately $1,350 by the installation of residual relays, and this would greatly reduce any damage due to faults on the high side of the transformers. This is the same type of relaying that is installed on all of the feeders from the K-25 Switchhouse and it has proven to be highly satisfactory in the past. This relaying improvement is shown in Part E of Figure Three.

F. K-25 "Variable Frequency" (Process) and Ring Bus Protection

The seven 13.8-kv "VF" buses which supply power to the K-25 process stage motors and the ring bus which permits the combining of these "VF" buses into various networks for flexibility of operation, have no primary relay protection. In case of certain types of faults, no back-up protection is available either, so that unusually severe and damaging failures could be experienced on these buses. Primary relay protection could be most economically provided on the VF buses and all but four sections of the ring bus by installing ground-fault bus relaying. The cubicles which enclose these buses and breakers are installed on insulated blocks and can be easily isolated from ground (except through the ground bus) and current transformers can be installed in the ground buses to initiate tripping. It would cost an estimated $12,600 to make these installations. The four sections of the ring bus for which ground-fault bus relaying is not practical, due to the housings being grounded in so many places, can be given protection by utilizing differential protection. This would cost an additional $13,100. Both of the relaying schemes are shown in Part F of Figure Four.

G. Improved Generator Protection

Phase overcurrent relays were never installed on the generators at the ORGDP generating station for several reasons. They are not considered a necessary or desirable addition in many cases, since fault currents can frequently be less than full-load or temporary overload currents. For example, if three generators were paralleled to several buses and one of them tripped out for some reason, it would be more desirable for the other two

V. Engineering Studies for Relay Improvements

G. Improved Generator Protection

to pick up all of the load, even with a frequency reduction, than for them also to trip out of service by overload relay action. If the first unit could not be restored to service in a short time, then process load reductions could be made in an orderly and discriminate fashion which would minimize production losses. In recent years a new type of relaying combination for generators has become accepted, which provides for back-up protection for bus faults or "close-in" faults (when the "primary" relaying doesn't isolate the fault) and which gives the generator protection against rotor overheating from 120-cycle currents induced in the rotor during phase-to-phase or unbalanced three-phase faults. This combination includes one negative sequence relay and one voltage-restrained, time-overcurrent relay per generator. This relaying for all ten generators would cost $8,500, and is shown diagrammatically in Part G of Figure Four.

VI. Engineering Studies for System Grounding

System grounding has also been studied extensively by the committee during this investigation, and as has been pointed out before, the committee found that there is a decided trend toward neutral grounding of all electrical power circuits. A number of papers from the Transactions and conference papers of the American Institute of Electrical Engineers were reviewed to obtain a better understanding of present day philosophy for the operation of ungrounded or grounded distribution systems. The desirable feature for operation of an ungrounded system is that service can be maintained to an essential load even with a single line-to-ground fault. A few moments warning before an outage can allow for finding faulted equipment or transferring the essential load to an alternate source or at least allow for an orderly shutdown. The ungrounded system offers some disadvantages which overshadow its usefulness. If a second ground occurs in another phase before the first is found, the result is an outage of two circuits with high values of fault currents at phase-to-phase magnitude. The reason the first ground fault may not have been eliminated in time is that it may not have been found. Ground detectors on an ungrounded system will indicate the existance of a ground fault but not its location. The single line-to-ground fault is seldom enough to actuate protective devices but it can do a certain amount of damage to electrical equipment and in some cases it may progress into a phase-to-phase fault. If no fault exists on an ungrounded system, the neutral floats at close to ground potential. A single line-to-ground fault causes line-to-line voltage to appear between the unfaulted phases and ground. This stresses the phase-to-ground insulation of the ungrounded phases to seventy-three percent higher than normal. If the single line-to-ground fault is not a solid one, an arcing ground can result which brings about a repetitive restrike overvoltage phenomenon peculiar only to ungrounded systems. These transient overvoltages can achieve the magnitude of five or six times normal voltage. This condition rapidly hastens the probability of a second ground fault, with a good possibility of many more at other points on the system.

The practice of grounding the system neutral is now well accepted. Low voltage

VI. Engineering Studies for System Grounding - Continued

systems, 600 volts and below, are most frequently solidly grounded. The medium-voltage class is commonly low-resistance grounded. Both of these methods result in the immediate tripping of a protective device should a ground fault occur thus isolating the faulted portion of the system. These two grounding methods are desirable from an equipment protective viewpoint but on a continuous operation basis is less desirable due to the immediate tripping of the faulted equipment.

Another form of system neutral grounding is high resistance grounding. This system uses the largest practical resistance in the system which results in a line-to-ground fault current of less than 0.1% of the three phase fault current. No means are provided for removing a faulted circuit for a single line-to-ground fault. Its application is made to a system where it is desired to limit the repetitive restrike overvoltage and some other overvoltage phenomena to a safe value but not trip-out a piece of equipment on the occurrence of a single line-to-ground fault.

Two additional types of grounding can be noted but their application is limited. One is the ground fault-neutralizer system which, by means of a reactor acting to neutralize system capacitance, sets up a resonant circuit during a ground fault. This limits the fault to nearly zero and causes the arc to go out. It is more expensive than other grounding methods and generally applied on systems above 15-kv where power transmission is by overhead lines. The other type is reactance grounding which is generally used on 480-volt grounded generators to limit their ground fault current to that of their three phase fault magnitude.

Table One taken from AIEE Conference Paper "System Neutral Grounding for Chemical Plant Power Systems" by Messrs. Brereton and Hickok gives a brief summary of system characteristics with various grounding methods.

In light of the experience of others and the recommendation of the switchgear manufacturer to ground the systems which are presently ungrounded, the committee reviewed the advantages and economics of several methods of grounding. It was found that "low-resistance", neutral grounding would be expensive for two reasons. First, the grounding transformers would be expensive due to the high values of ground-fault current inherent with this type of grounding, and, second, sensitive ground relaying should be installed as a part of the low-resistance grounding installation. "Corner-of-the-delta" grounding was also considered and rejected. This type of grounding does not require expensive grounding transformers, since one phase is solidly grounded, but it would require relaying changes and in some cases permissible fault currents would have exceeded breaker interrupting capacities.

"High-resistance", neutral grounding was finally chosen by the committee for installation on some systems because of its low cost, adaptability to present relaying, and its effectiveness in limiting the magnitude of transient overvoltages. The cost to install high-resistance grounding, with an alarm to indicate the flow of current through the neutral resistor, is shown in Part A of

TABLE ONE

SYSTEM CHARACTERISTICS WITH VARIOUS GROUNDING METHODS

	Ungrounded	High Resistance Grounding	Low Resistance Grounding	Solid Grounding
Properties during faults				
Current for a phase-to-ground fault in percent of 3 phase fault current	Less than 0.1%		5% to 10%	About 100%
Transient overvoltages	Up to 6 times	Not more than 1-1/2 to 2 times normal		
Automatic segregation of faulty circuit and equipment	No		Yes	
Circuit outage for various types of system faults: One ph. to ground	No outage		Outage	
Circuit outage for various types of system faults: Phase-to-phase, Two ph. to ground, Three phase	Outage			
Multiple Faults	Many case studies reported showing multiple failures	Report of insignificant number of failures showing multiple outages.		
Power System Properties				
Transformer; winding connection	Delta	Wye or delta with grounding transformer		
Fault Location Method	Have to take part or all of the system out of service or use ground fault locator to find ground faults		System does not have to be taken out of service because the faulty equipment has been automatically isolated	
	If ground fault is not removed, may lose two circuits due to another ground fault		Ground faults are localized and trip off immediately	
First Cost: Low voltage systems	Delta Connected Substation with ground detector generally costs more than wye	Slightly higher due to high resistance resistor and ground indicator	Not generally applied, but would be slightly higher	Lowest, in that wye and delta transformers cost about the same.
First Cost: Medium voltage system	Including ground detector equipment delta is slightly lower in cost	Somewhat higher due to high resistance grounding equipment	Somewhat higher due to low resistance grounding equipment	Wye connected substation slightly higher than delta
Maintenance Cost	Takes time and equipment to find grounds		Ground faults are easily located	
Rating of lightning arresters	Ungrounded neutral type			Grounded-neutral type
Application of grounding method	Less and less frequently applied	Applied on low or medium voltage systems when system not permitted to be tripped for first ground fault	Applied on medium-voltage systems i.e., 2.4, 4.16, 6.9, or 13.8 KV	Applied on low-voltage systems i.e., 208, 240, 480, or 600-Y Some application on small medium voltage systems.

[redacted]

VI. Engineering Studies for System Grounding - Continued

Table Two. Part B of this table presents a cost comparison between installing high-resistance grounding and installing low-resistance grounding, with improved ground relaying, for the K-27 and K-29 stage-motor networks. The low-resistance grounding costs about twenty-one times as much to install on the existing systems as does high-resistance grounding.

VII. Evaluation and Recommendations

A. 13.8-KV Systems

The most likely causes for the failure in ACB 53-E have been given by the manufacturer to be weakened surface insulation on the solid insulation parts, and the presence of transient overvoltages. There is little that can be done to further limit the magnitude of any overvoltages, since these systems are already grounded through low-resistances, except to eliminate the initiating source of the overvoltages. It is believed that by grounding the 2300-volt systems in the auxiliary switchhouse, the source of any overvoltage which contributed to the fault in ACB 53-E will be largely eliminated. However, the greatest deterrent to recurrences of faults in the Westinghouse CA breakers is probably the maintenance of high insulation strength on the Micarta parts of the breakers and the locating of any insulation weaknesses before failures occur. Therefore, the committee recommends that present efforts to evaluate suitable tests for the detection of deteriorated insulation be continued and that if a satisfactory, non-destructive test can be found, such tests be made a part of the biennial overhaul-testing program. The committee also recommends that the investigation of breaker failures at K-31 be continued to determine the cause of these breakers experiencing faults through the air insulation of the breakers. There is still the possibility there may be similarities between these failures and the one in ACB 53-E.

The committee recommends that ground-fault bus or differential relaying, as outlined previously, be installed on the "Variable Frequency" and ring buses at the K-25 Switchhouse, to limit the damage which any faults on these buses might inflict.

Residual ground relays should be installed to improve the protection to the high-voltage windings of the auxiliary transformers and voltage-restrained, time-overcurrent and negative-sequence relays should be installed to provide back-up relaying for the 13.8-kv networks and to improve the generator protection.

These recommendations call for an immediate total expenditure for the 13.8-kv systems of $35,550.

B. 2300-Volt Systems

The committee believes that there is ample reason for assigning major responsibility for the initiation of the fault in auxiliary transformer No. 2

[redacted]

[redacted]

TABLE TWO

Part A

COST TO INSTALL HIGH-RESISTANCE NEUTRAL GROUNDING (Including ground-detection alarm, but not including relay tripping.)

I. 2300-Volt Systems

Building No.	Building Description	Number of Trans. of Networks		Total Cost
K-707	K-25 Auxiliary Switchhouse	3		$ 6,880
K-761	K-31 Switchhouse	2		4,440
K-791	K-33 Switchhouse	2		4,440
K-802	K-25 Pumphouse	2		4,440
K-832	K-27/K-29 Pumphouse	1		2,220
K-1002	Administration Area	1		2,220
K-1101	K-25 Air Plant	5		11,100
			Total	$ 35,740

II. 480-Volt Systems

Building No.	Building Description	Number of Trans. of Networks		Total Cost
K-25	K-25 Process and Auxiliary	195		$ 65,910
K-402	K-27 Process and Auxiliary	30		10,140
K-502	K-29 Process and Auxiliary	18		4,580
K-602	K-31 Auxiliary Networks	6		1,928
K-902	K-33 Auxiliary Networks	8		2,704
K-707	K-25 Auxiliary Switchhouse	3		1,014
-	All Others	63		21,294
			Total	$107,570

Part B

COMPARISON OF COSTS TO INSTALL HIGH-RESISTANCE NEUTRAL GROUNDING AND LOW-RESISTANCE GROUNDING, WITH SELECTIVE TRIPPING OF MOTOR GROUPS (CELLS), ON THE K-27 AND K-29 STAGE MOTOR NETWORKS.

Building No.	Number of Networks	High-Resistance Grounding Cost	Low-Resistance Grounding Cost
K-27	25	$ 8,450	$ 177,500
K-29	15	3,810	106,500

[redacted]

VII. Evaluation and Recommendations

B. 2300-Volt Systems - Continued

2300-volt secondary breaker to the lack of system grounding, and the committee recommends that high-resistance neutral grounding be installed on these systems. Since all but one of the other 2300-volt systems at ORGDP supply essential services to recirculating water pumphouses, electrical switchhouses, and instrument air plants, whose shutdown would affect all or large portions of the cascade, it is recommended that all 2300-volt systems be grounded also, using the high-resistance neutral grounding design.

The extensive damage to the 2300-volt secondary breaker, the adjacent breakers on either side of the secondary breaker, and the bus, clearly demonstrate what can happen where full protection to electrical equipment is not provided. The committee believes the relaying improvements outlined previously would be a wise investment in electrical protection and it recommends that these improvements be installed.

The suggestion of the manufacturer to perform 15-kv a-c high potential tests on the Westinghouse DH breakers used in the auxiliary switchhouse on the 2300-volt systems should be made a part of the overhaul-testing program, unless a superior method of testing for deteriorated insulation can be found.

These recommendations would require that $104,200 be spent for system or equipment changes.

C. 480-Volt Systems

The committee believes that the two experienced faults in K-29 stage-motor switchgear amply demonstrate the need for improvement on these systems. Since system grounding is the only design change so far advanced that appears to offer major reduction in the possibility of future recurrences of the initiation of bus faults, the committee recommends that these systems be grounded. The other 480-volt systems in the Oak Ridge Gaseous Diffusion Plant are of smaller size and capacity and have been relatively trouble-free for many years. The committee recommends that these systems, which include the auxiliary 480-volt systems of K-29, not be altered at this time. If future experience with the K-29 stage-motor networks after they have been grounded is good, and there is evidence that grounding of the other 480-volt networks is economically justified, either by increasing the life of system insulation or preventing costly equipment replacements due to failures, system grounding could then be installed on these other systems. To install high-resistance, neutral grounding on the fifteen stage-motor networks at K-29 would cost approximately $3,810.

D. All Systems

The committee recommends that the protective schemes of all electrical power

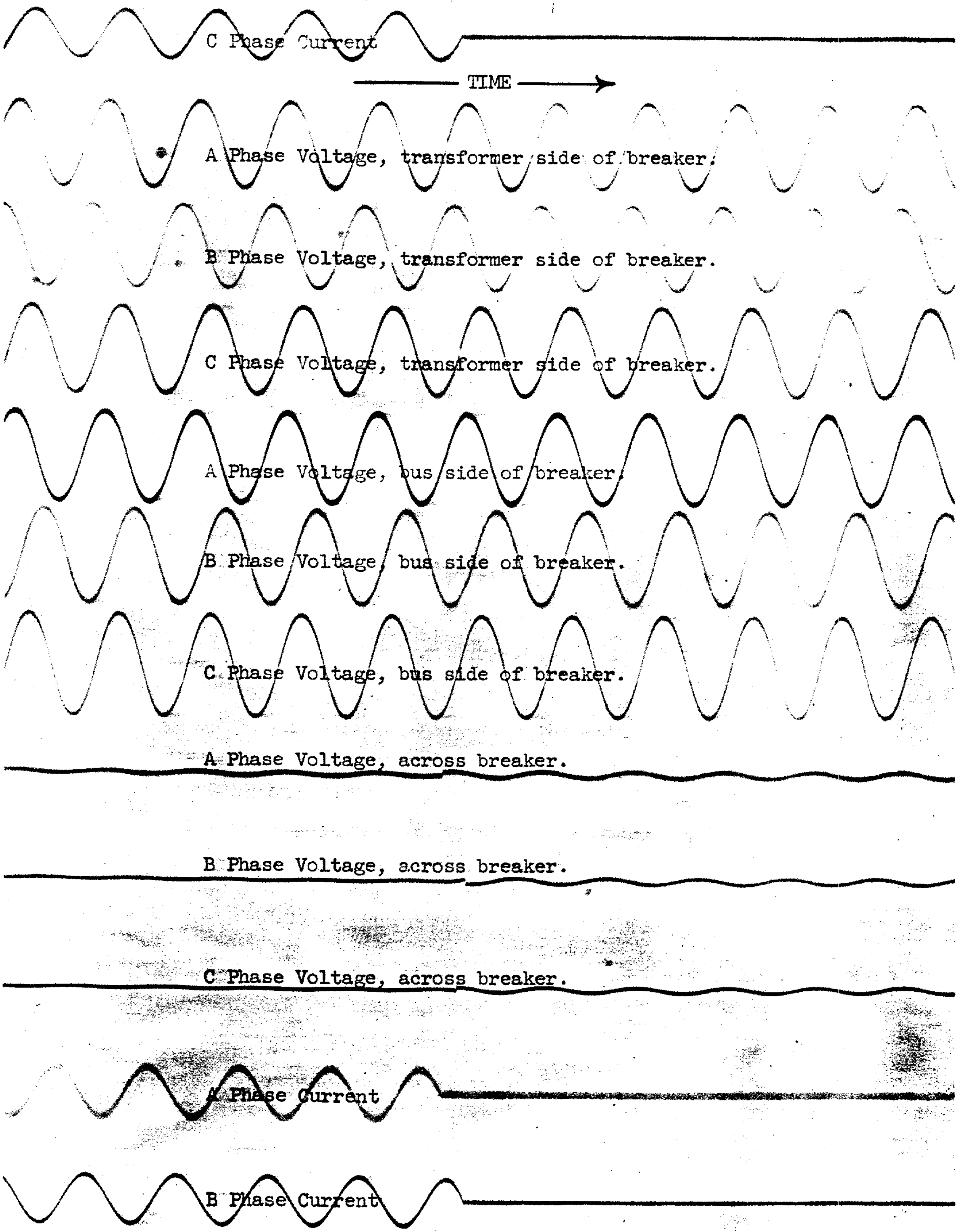
[redacted]

VII. Evaluation and Recommendations

D. All Systems - Continued

systems be periodically reviewed to ensure that necessary changes in protection will accompany loading or system changes. The committee also recommends that the design of new electrical systems, or major revision of existing electrical systems, include low-resistance grounding and the more sensitive relaying possible on this type system, as a part of the design. The electrical systems for the K-31 and K-33 process stage-motors are of this design and have proven to be highly satisfactory. It has been found, for instance, that the damage to failed motors is so slight that the location of the fault many times is hard to find and that cost of repairing the failed motors is, therefore, considerably less than where insensitive relaying has permitted faults to inflict severe damage before being isolated.

[redacted]



Typical oscillogram showing voltage-to-ground on each side of K-31 ACB 405, Voltages Across the Breaker, and Line Currents Through the Breaker, during a normal opening cycle, made on March 24, 1959.

Figure One

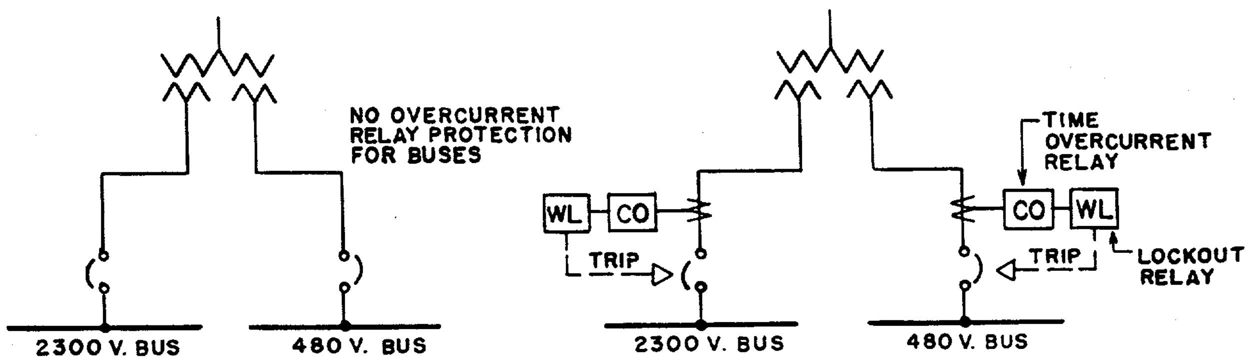
FIGURE TWO

SCHEMATIC DIAGRAMS OF RELAYING IMPROVEMENTS

A. RELAY PROTECTION FOR POWERHOUSE 2300 VOLT MOTORS

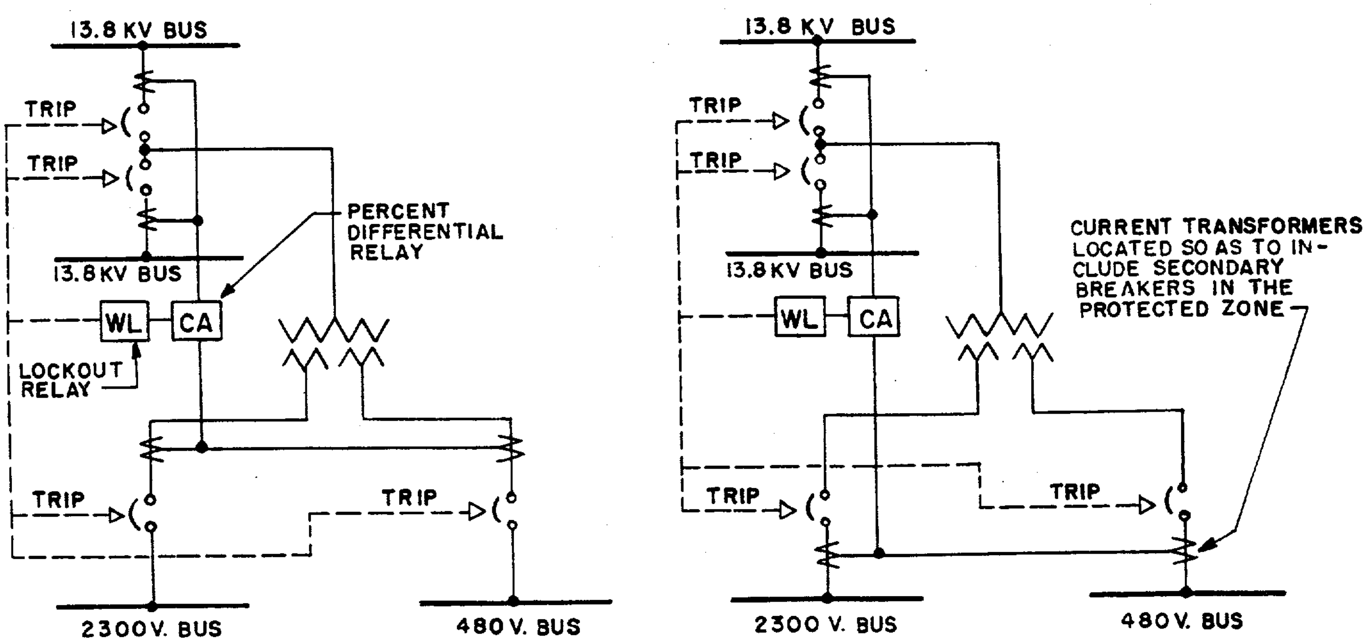
PRESENT PROPOSED

B. AUXILIARY TRANSFORMER SECONDARY BREAKER OVERCURRENT RELAY



PRESENT PROPOSED

C. DIFFERENTIAL RELAYING FOR AUXILIARY TRANSFORMERS

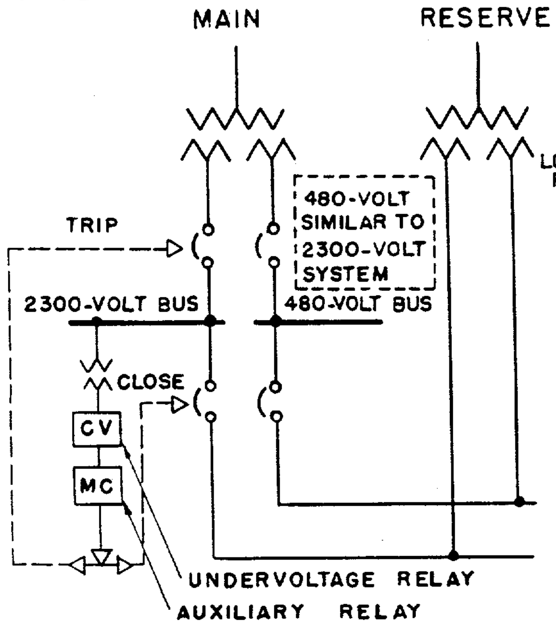


PRESENT PROPOSED

FIGURE THREE

SCHEMATIC DIAGRAMS OF RELAYING IMPROVEMENTS

D. LOCK-OUT RELAYS FOR AUTOMATIC THROW-OVER SCHEMES ON AUXILIARY BUSES



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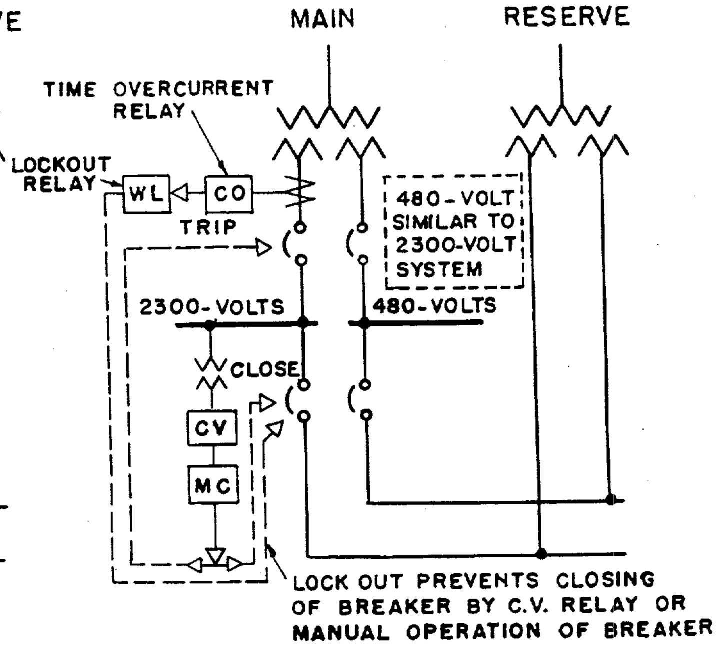
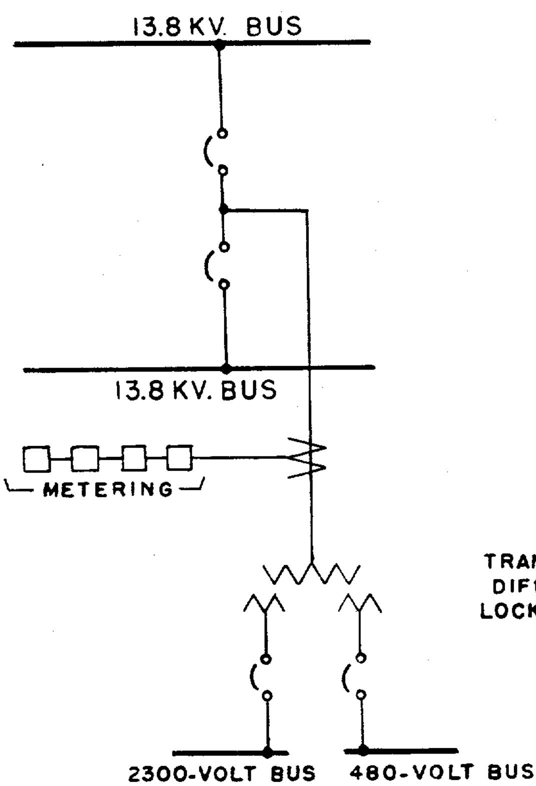


PROPOSED

E. GROUND RELAYS FOR HIGH-VOLTAGE WINDINGS OF THE AUXILIARY TRANSFORMERS



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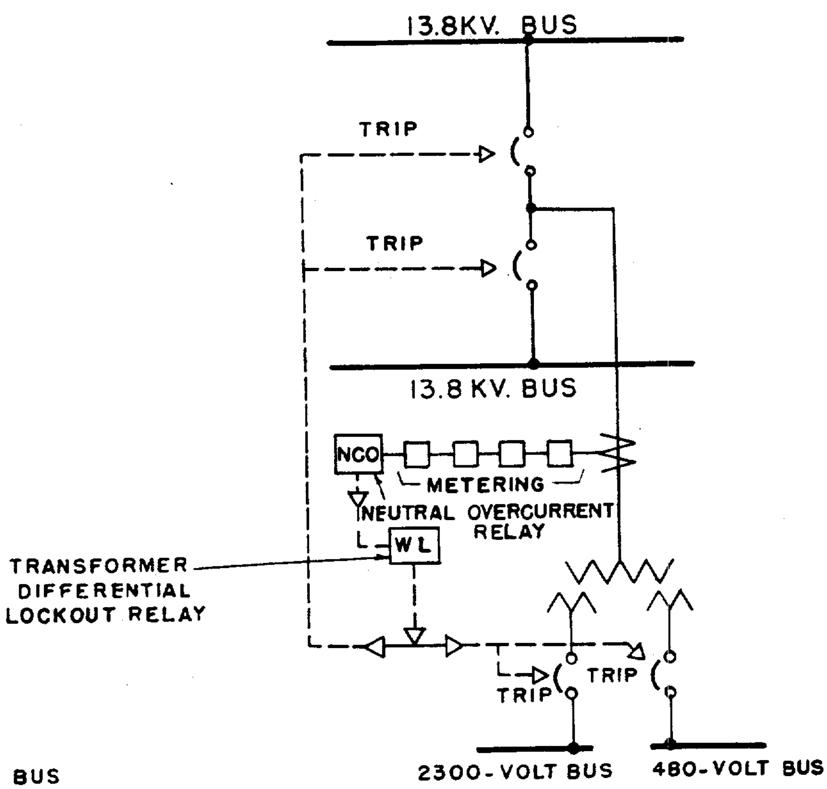
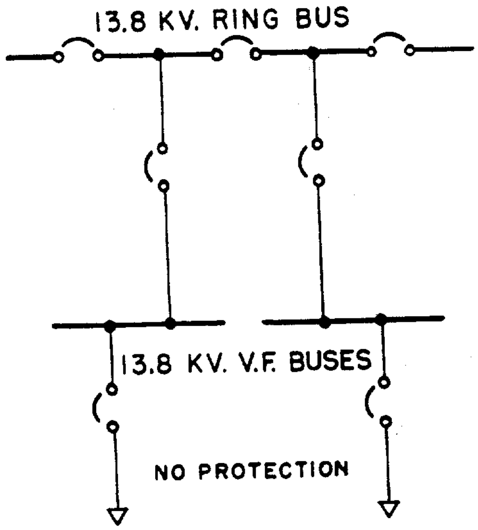


PROPOSED

FIGURE FOUR

SCHEMATIC DIAGRAMS OF RELAYING IMPROVEMENTS

F. K-25 "VARIABLE FREQUENCY" AND "RING" BUS PROTECTION



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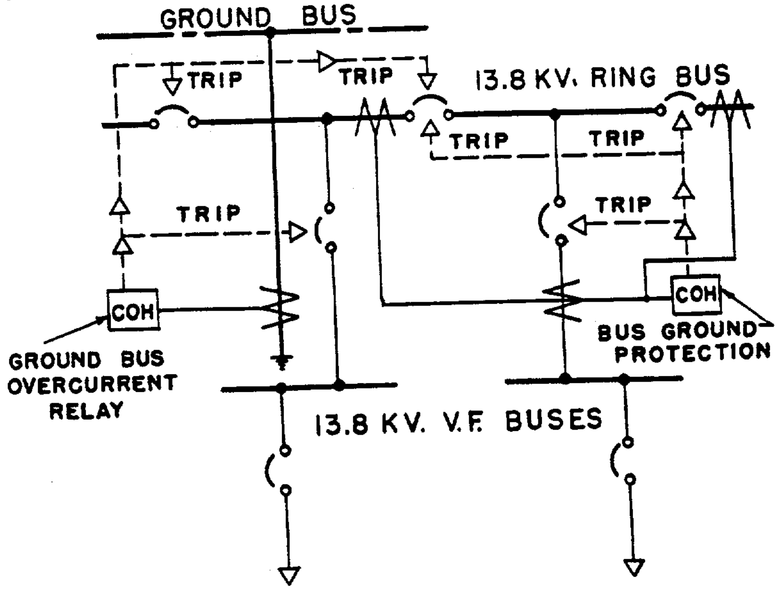
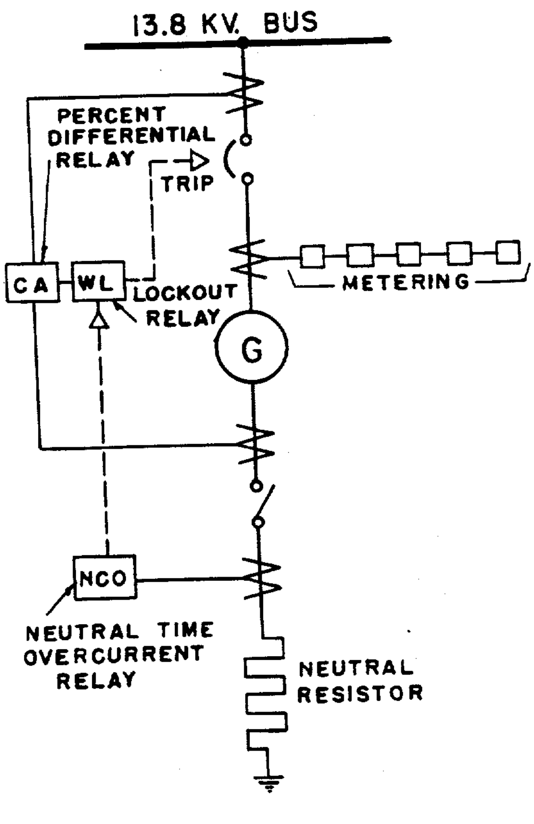


PROPOSED

G. IMPROVED GENERATOR PROTECTION



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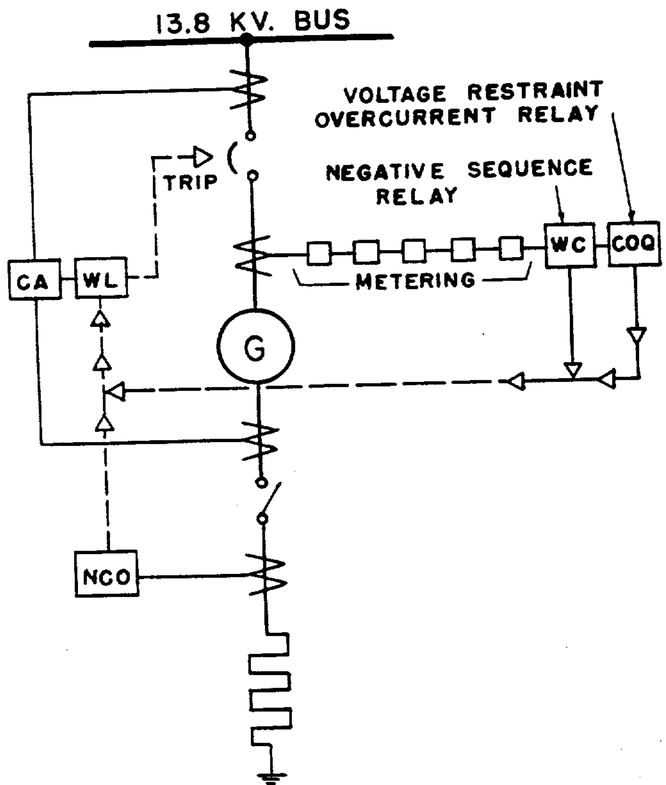
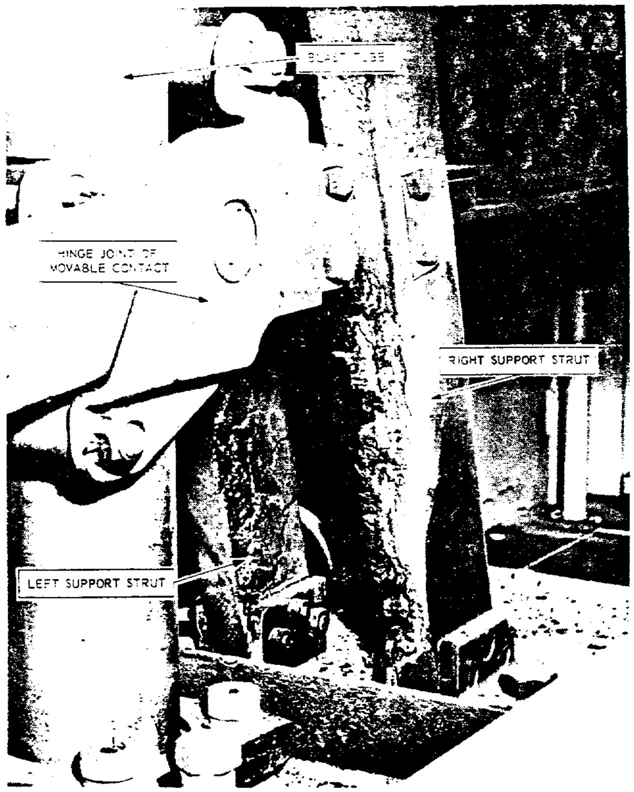
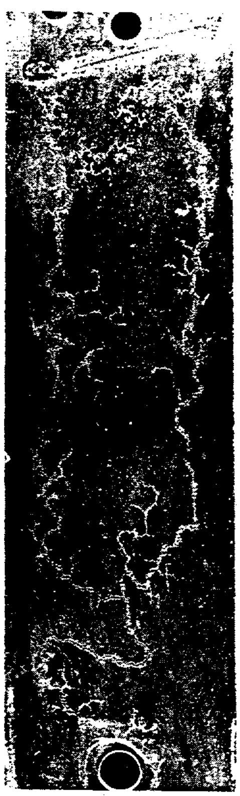


PROPOSED



Photograph One

PHOTOGRAPH SHOWING DAMAGE TO BLAST TUBE SUPPORT STRUTS ON ACB 50E, MIDDLE PHASE.

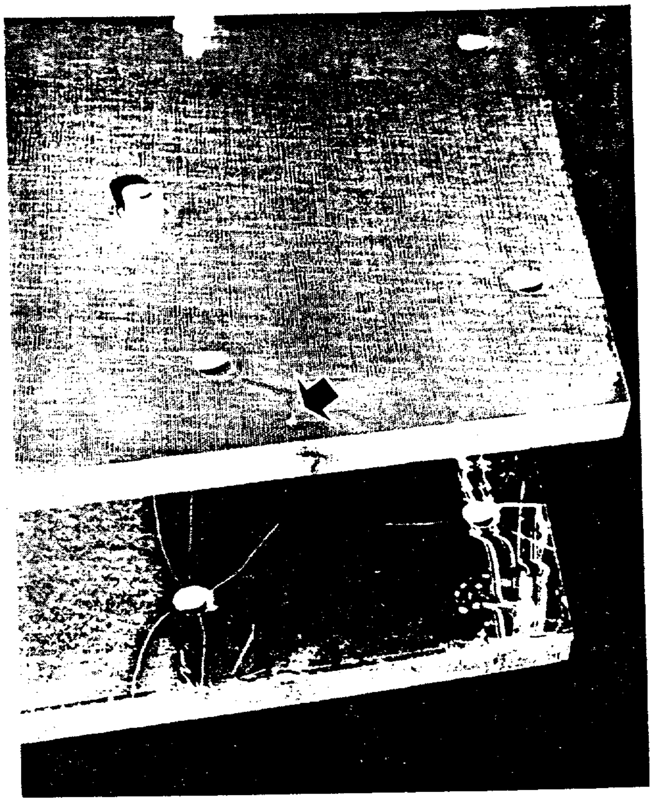


Photograph Two

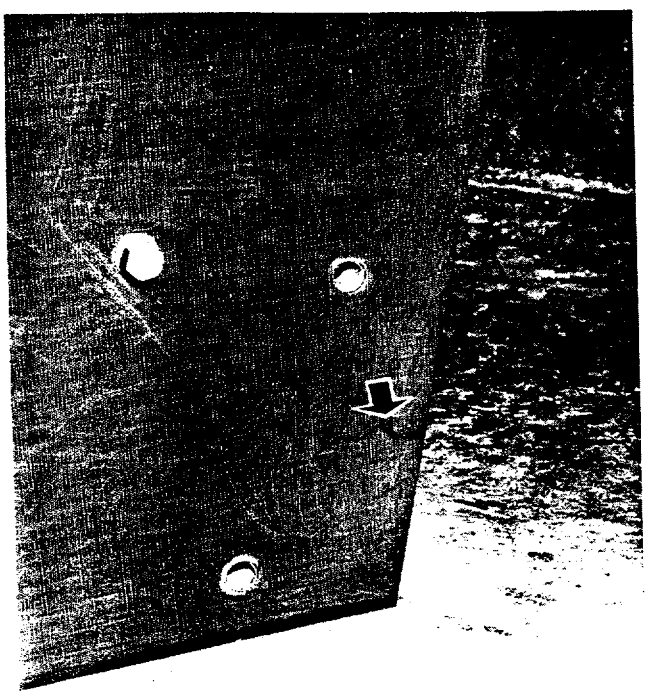
OUTSIDE SURFACE OF LEFT SUPPORT STRUT ACB 50E

Photograph Three

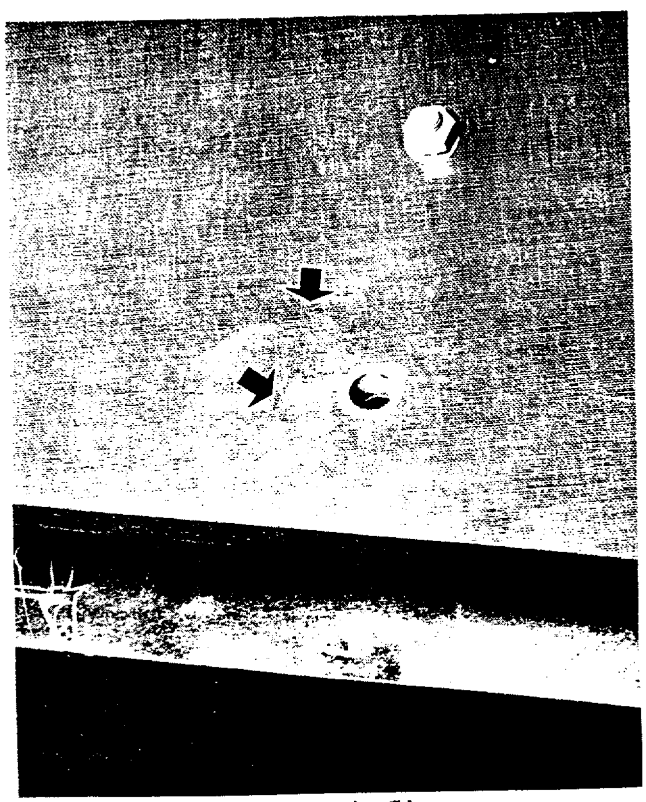
INSIDE SURFACE OF RIGHT SUPPORT STRUT ACB 50E



Photograph Four



Photograph Five



Photograph Six

PHOTOGRAPHS SHOWING TRACKING ON SURFACES OF
ARC SHOOTS CAUSED BY CORONA

[redacted]

INSTRUMENT AIR SYSTEM INVESTIGATION

Review of Instrument Air Failure Cause

Following the Power and instrument air failure of January 17, 1959, the switchgear to the emergency instrument air compressors was carefully inspected and tested to determine the cause or causes for its failure to function properly during the power outage. The reduced-voltage starting switch to the first stage compressor was found stuck in mid-position. After freeing the switch, observations were made of the operation of the switch with a portion of the cubicle paneling removed during several starting cycles and it was noted that switch "chattered" or "pumped" during initial stages of motor starting. This was found to be due to the drop in generator (driven by the diesel engine) voltage caused by the heavy inrush of current. This characteristic of the equipment has probably existed since its installation, but had not been noticed before due to the very high noise level in the air plant when test runs were being made and the fact that switch operation could not be visually observed. In spite of the chattering of the switch, it had always started the compressors on the previous 55 or more periodically scheduled test runs in an apparently satisfactory manner.

Improvements to Date

As was stated in the interim report, a number of steps have already been taken to improve the operation of the switchgear for the emergency air compressors. Briefly, these consisted of installing removable Plexiglass windows to permit observation of switch operations and permit rapid accessibility in case of mechanical failure, raising the generator voltage from 2400-volts to 2600-volts to reduce the chattering of the starting switches, and providing push buttons for manual starting in case of automatic control-circuit failures. Lower-voltage solenoids for the starting switches have been ordered and will be installed.

Recommendations

The operation of the starting switches, after the lower-voltage solenoids have been installed, should be carefully observed. If completely satisfactory and dependable operation is not obtained, switchgear of a more dependable design should be installed for this most important emergency equipment.

The committee still feels that the essentiality of the instrument air system to the operation of the ORGDP cascade warrants the expenditure of $23,415 to provide electrical facilities to utilize diesel-generator power for the four 730-cfm Worthington reciprocating compressors and to modify one of the present 13.8-kv feeders to the K-1101 air plant and the K-25 pumphouse to feed from K-27 switchhouse (instead of K-25) for an alternate source of power to the normal equipment. Preliminary design work for these changes is in progress and the changes should be completed as soon as funds can be authorized for this work.

These recommendations are described in detail in the interim report of the committee.

[redacted]

[redacted]

CASCADE EQUIPMENT INVESTIGATION

No equipment additions or emergency procedural changes are recommended by the committee. Concentrated efforts should be made to detect and remove grounds from ungrounded systems as soon as practical, since serious faults can result if a second ground should develop on another phase or if the first ground should become an intermittent ground. Protective devices should be set where they will operate to isolate all possible faults before heavy damage to the equipment results, even though there may be some chance for undesirable or false tripping. There may be some exceptions to this practice, but the risks involved should be carefully evaluated. When the electrical equipment is new and there is little chance of insulation failures, high relay settings to minimize false relay tripping may be an economically sound practice, but as the equipment gets older and insulation failures become more frequent, more attention to adequate fault protection is certainly warranted, and there should be economical justification for a more tolerant philosophy toward equipment trip-outs.

A complete account of the effect on the cascade of the total power failure to the K-25 building and the instrument air failure is given in the interim report of the committee.

[redacted]

[redacted]

FIRE CONTROL INVESTIGATION

Smoke Evacuation

The insulation fires, created by the January 17 electrical failures in the K-25 Switchhouse (K-704 Building) and the Auxiliary Switchhouse (K-707 Building), gave off large quantities of black smoke, which was a serious handicap to the operating personnel in determining what had happened, and to the fire fighting personnel in combating the fires. During the early phases of this incident the difficulty was caused by the lack of power to operate the ventilating systems. However, after the power had been restored to service and the ventilating systems had been restarted, the smoke continued to fill the galleries where the failures had originated. This was probably due to the fact that the ventilating systems were not changed, following the restoration of power, to give the best evacuation of the smoke. The outside temperature at the time of the failure was a little below freezing and the ventilating systems for the galleries were set up for "winter" operation. This meant that the recirculating dampers in the intake-air fan penthouses were open and the outside-air, intake dampers were closed. Since the operating personnel were concentrating their attention on switching operations, and for the most part, emergency personnel from other sections of the plant, who were unfamiliar with the operation of the ventilating systems, were used in the fire fighting activities, these ventilating systems for the switch galleries were not operated to the best advantage. This situation can and will be corrected through training of personnel.

The most practical ways for providing emergency ventilation during power failures for the switchgalleries of the K-25 Switchhouse and Auxiliary Switchhouse, the K-27/K-29 Switchhouse, and the K-31 Switchhouse were thought to be those which supplied emergency power to the normal ventilating equipment. This emergency power for the K-27/K-29 and K-31 Switchhouses could be supplied from existing diesel generators in the K-29 and K-31 process buildings. However, even with this arrangement, it was found that an expenditure of $24,707 would be required to install the necessary cables and controls to furnish emergency power to the existing ventilating fan motors in those two switchhouses. It was found that the most economical manner to supply emergency ventilation to the K-25 Switchhouse and Auxiliary Switchhouse was to install transformers on Feeder 319 (an emergency source of power from the substation supplying the Oak Ridge National Laboratory) for supplying emergency power to the normal ventilating fan motors. This would cost an estimated $10,366.

A number of other schemes for providing emergency ventilation were also considered. Small diesel motors coupled directly to the individual fans, and portable diesel-electric units to power existing ventilating fans or newly installed ventilating fans located strategically in the building walls were some of these. All of these other schemes were found to cost more, provide inadequate ventilating systems, or have other undesirable characteristics.

[redacted]

[redacted]

Floor Drains

Following the extinguishment of the fires in the switch galleries of the K-25 Switchhouse and Auxiliary Switchhouse, considerable quantities of water had to be removed before some of the electrical equipment could be safely restored to service. Since none of the galleries in any of the ORGDP switch-houses has floor drains, the water had to be moved with squeegees or brooms to a building expansion joint or a stairwell to remove it from the gallery floor. To improve this situation, consideration was given to the installation of two floor drains per switch gallery, on the top floor and on the ground floor. The most logical location for the two drains would be to install one on either side of the row of breaker cubicles, near the middle of the gallery. The proposed plan called for piping the drains on the top floor to the out-side walls and the ground floor drains would empty directly into the basement, which already has a number of drains. It was estimated that such installations would cost $19,880 for the four switchhouses being considered.

Conclusions and Recommendations

Since it would cost approximately $54,953 to install emergency ventilation and floor drains in the K-25 Switchhouse and Auxiliary Switchhouse, the K-27/K-29 Switchhouse, and the K-31 Switchhouse, the committee felt that such an expenditure was not justified. Not all switchgallery fires would be expected to be coincidental with a total power failure to the ventilating equipment, nor could emergency ventilation be installed in all locations where insulation fires are probable. The resulting delays in equipment downtime due to water removal from switchgallery floors which have been experienced in the past do not seem to warrant the cost of drain installations. The committee does consider these problems to be of sufficient concern that they should re-ceive the continuing attention of operating and emergency personnel. Emer-gency plans should be kept up to date and emergency personnel well trained to utilize existing equipment and materials in the most effective and safe manner practical.

[redacted]

[redacted]

KP-1633
Supplement
Appendix A

APPENDIX A

PLEASE NOTE: APPENDIX A (EXCEPT for 2 pg ltr in Appendix
IS A WESTINGHOUSE
REPORT AND CANNOT
BE RELEASED BY LOCKHEED
MARTIN. J. LAMB WILL REVIEW
TO DETERMINE IF REPORT
IS STILL NEEDED

A G Thornton
1/24/96

[redacted]

UNION CARBIDE NUCLEAR COMPANY
DIVISION OF UNION CARBIDE CORPORATION

UCC

POST OFFICE BOX P
OAK RIDGE, TENNESSEE

March 4, 1959

Westinghouse Electric Corporation
Assembled Switchgear & Devices Engineering
East Pittsburgh, Pennsylvania

Attention: Mr. W. C. Fulton

Dear Sirs:

Electrical Faults in CA, DH, and DA
Breakers at the Oak Ridge Gaseous Diffusion Plant

Your prompt report of February 12, 1959 covering your analyses of the electrical faults which we have experienced recently in equipment manufactured by you was appreciated and most helpful. Some items were discussed during our meeting with your personnel in East Pittsburgh on February 3, 1959 which were not covered in your report. Some of these are significant to us and we would appreciate receiving your written comments to our understanding of the discussions on these items.

There was considerable discussion on the amount and kind of lubricant to use on breaker contacts and rack-in studs. It was your expressed opinion that the type of lubricant we were using was satisfactory; that a minimum amount should be used; that a thin coating of lubricant should be applied and then wiped off with a clean rag; that more satisfactory service might be obtained on rack-in studs and fingers on DH and DA breakers if no lubricant at all were used, since the lubricant sometimes acted as a collector for abrasive particles; and that although there was an excessive amount of lubricant on ACB 60-E tie-breaker, this probably did not contribute to the faulting of the middle phase through air to the cubicle door. (We now believe the thick smoke from the fires in ACBs 53-E and 54-E, which was present inside this breaker at the time, was probably responsible for this failure.)

Your Power Circuit Breaker Engineering personnel stated in the meeting that the varnish on the Micarta and wooden parts of the 13.8-kv breakers should have a high glossy appearance and that if the finish became dull, the old varnish should be sanded off and the parts revarnished. It was also recommended that 37.5-kv a-c high potential tests be performed on each breaker following their biennial overhaul and inspection; that these high potential tests should be made both between the phases and ground, as well as across the breaker contacts with the breaker in the open position; and that our overhaul and inspection schedule of once each two years was adequate. You were also asked about the desirability of making contact resistance measurements (using a "Ductor") as a part of the testing following the maintenance of the breaker, and it was felt this would be worthwhile, although a voltage drop test across the breaker with the contacts carrying rated current would be better, if it was a practical test to make in our switchhouses (which it is not).

One of the contributing causes of the failure of the 13.8-kv ACB 53-E was thought to have been the presence of high voltages of frequencies above 60 cps which were transmitted through the auxiliary transformer from the arcing taking place on the 2300-volt bus. You were asked why these high voltages did not appear on the oscillogram and explained that the potential transformers which supply voltages to the oscillograph would attenuate these voltages greatly and that the galvanometer elements of the oscillograph might not have been responsive at those frequencies. When future tests are being conducted at K-31 on normal ACB operations, you requested that the voltages supplied to the oscillograph galvanometers be obtained from resistance dividers and that galvanometers with good response up to frequencies above 3500 cps should be used.

There was some discussion about whether or not the fuses installed in the 480-volt networks in our K-29 Building would provide proper protection, but Mr. F. A. Lehmann has already sent some data back to Mr. Raczkowski for his evaluation and comments, so no further information on this discussion would be necessary.

Since our meeting with you, a question concerning the high-potential testing of the 13.8-kv breakers has arisen which we would also like to have your comments on. Is there any danger of causing a serious fault during the 37.5-kv high-potential test by causing arcing across the disconnect switch to an energized bus, transformer, feeder, or generators? The voltages across the disconnect switch might be 180° out of phase and add up to 14.0 plus 37.5, or 51.5-kv. Should rubber blankets or other insulating material be placed between the disconnect switch contacts?

Very truly yours,

UNION CARBIDE NUCLEAR COMPANY

L. L. Anthony
Electrical Operations Department

LLA:es

cc: Mr. R. L. Cawthon, Knoxville, Tennessee
Mr. J. B. Nuchols
Mr. H. G. P. Snyder
File